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# Radiation and Society

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On Sept. 9-10, Dr. Yalow visited Macalester College as part of the college's Wallace Distinguished Visitors Program. In her public address, "Radiation and Society," she discussed many of the issues presented in this article. This article will be published in German in the German publication *Nobelpreisträger in der Naturwissenschaftlichen Rundschau* later this year. It is printed here with the permission of Dr. Yalow and the German publisher.

## Introduction

We live in a world in which the perception of reality is too often confused with reality and there are few fields in which more confusion exists than in the popular perception of the hazards of exposure to low-level radiation and low-level radioactive wastes. Much of the fear of radiation has been generated by the association of radiation and radioactivity with nuclear explosions and nuclear war. So phobic is the fear that, in the United States at least, the old dream of "Atoms for Peace," including the use of nuclear reactors for power production and even the use of radioactive materials in biomedical investigation and clinical medicine, is threatened. This review will discuss a selection of relevant papers that describes some of what we know about the health effects and, in particular, the possible carcinogenic effects associated with low doses of ionizing radiation delivered at low dose rates.

## Radiation Units

Before discussing radiation effects, let me define some units. A rad is a unit of absorbed dose or energy absorbed per unit mass from ionizing radiation and corresponds to 100 ergs/gram (0.01 joules/kg). Densely ionizing radiation such as that associated with  $\alpha$  particles, protons, or fast neutrons is more effective in producing deleterious biologic effects than is the lightly ionizing radiation associated with  $\beta$ ,  $\gamma$ , or X-radiation. A rem is a unit that takes into account the relative biologic effectiveness (RBE) of lightly (low linear energy transfer, LET) and densely (high LET) ionizing radiation. Rad and rem are used interchangeably for low LET radiation. However, the RBE is not a constant for any ionizing particle but depends to some extent both on its energy and the biologic effect under observation.

## Natural Background Radiation

It must be appreciated that environmental radiation from natural sources has always been with us and is our principal source of radiation exposure. This exposure arises from cosmic radiation, our self-contained radionuclides (the

radioactive isotope of potassium ( $^{40}\text{K}$ ) with a half-life of  $1.3 \times 10^9$  years, naturally occurring  $^{14}\text{C}$ , and the daughter products of the uranium, thorium, and actinium families) and the natural radioactivity of the soil and building materials. The average whole body natural background radiation dose in the United States is considered to be about 0.1 rem per year. However, the yearly exposure can vary 10-fold around the world. Cosmic radiation increases at higher elevations, and in Brazil, India, and elsewhere there are areas with naturally highly radioactive soils. For instance, in the Rocky Mountain regions of the United States, the population receives on the average approximately an additional 0.1 rem/year compared to the rest of the population. Frigerio and Stowe (1) have observed that the cancer rates in the seven states with the highest background radiation are about 15% less than the average U.S. rates. A more recent study that took into account possible complicating factors such as industrialization, urbanization, and ethnicity appeared to confirm a deficit in cancer mortality in high altitude regions (2). Data such as these might suggest a protective effect of excess radiation delivered at low dose rates, although other factors might be considered. Nonetheless, had the cancer incidence or mortality been greater in the Rocky Mountain states, radiation effects, rather than other environmental factors, would have been unequivocally declared by some to be the causative agent. In the Rocky Mountain states, cumulative excess exposure averages about 1 rem for each decade of residence. Thus, even in a group as large as five million persons receiving this excess radiation exposure, genetic and/or lifestyle factors are of such overwhelming causative importance that one cannot attribute variations of cancer incidence or mortality either to advantageous or to deleterious effects of low dose/low dose rate radiation.

Are there other more sensitive indicators of abnormalities apart from malignancies induced by increased natural background radiation? Such a study was performed in China by examining 150,000 Han peasants with essentially the same genetic background and lifestyle (3). Half of those studied lived in a region where they received an almost three-fold



higher radiation exposure because of radioactive soil. More than 90% of the progenitors of the more highly exposed group had lived in the same region for more than six generations. The investigation included determination of radiation level by direct dosimetry as well as an evaluation of a number of possible radiation-related health effects. This study failed to find any discernible difference between the inhabitants of the two areas in chromosomal aberrations of peripheral lymphocytes, frequencies of hereditary diseases and deformities, growth and development of children, and status of spontaneous abortions as well as in the frequency of malignancies. The authors of this study concluded that either a practical threshold for radiation effects exists or that any effect is so small that the cumulative radiation exposure to three times the usual natural background resulted in no measurable harmful effects in the population after six or more successive generations. Similar negative studies have been reported from high natural background areas in Brazil and Kerala.

### High Levels of Radiation Exposure

Much of what we have learned about the biologic effects of radiation has been obtained from studies of those exposed at high doses and dose rates. The 82,000 survivors of the Hiroshima-Nagasaki bombings were the largest group ever exposed to virtually instantaneous high doses of whole body radiation. In this group, whose exposure averaged 27 rem, the incidence of malignancies through 1978 was only about 6% greater than would have occurred without the radiation exposure. That is, 4,500 cancer deaths would have been expected in an unexposed population and an additional 250 cancers deaths, 90 of which were from leukemia, were estimated to be a consequence of the radiation (4). The increased incidence of leukemia was most visible since it peaked at five to nine years after the bombing and decreased thereafter.

Those treated with  $^{131}\text{I}$  for hyperthyroidism are probably the largest group receiving iatrogenic whole body radiation. It has been estimated that by 1968 more than 200,000 patients were so treated in the United States alone (5). A study of 36,000 such patients from 26 medical centers, of whom 22,000 were treated with a single dose of  $^{131}\text{I}$  and most of the rest with surgery, revealed no difference in the incidence of leukemia between the two groups (5). The average bone-marrow dose was estimated to be about 10 rems, more than half of which was delivered within one week. The follow-up for the  $^{131}\text{I}$ -treated group averaged seven years, quite long enough to have reached the peak incidence for leukemia, as had been determined from the Hiroshima-Nagasaki experience (4). A subsequent follow-up of the hyperthyroid patients three years later continued to reveal no difference in leukemia rates between the two groups (6). This study emphasizes the importance of having an appropriate control group since hyperthyroidism per se appears to be associated with an increased incidence of leukemia independent of the mode of therapy.

There has been considerable concern with the potential release of  $^{131}\text{I}$  as a consequence of reactor accidents, which might be followed by an increased incidence of thyroid cancer. It should be appreciated that measurement of thyroïdal uptake of  $^{131}\text{I}$  was the method of choice for the diagnosis of thyroid disease for a quarter century before radioimmunoassay of thyroid-related hormones became generally available in the 1970s. Estimates suggest that in

the United States alone approximately one to three million people received thyroïdal doses in the range of 50 to 100 rems as a consequence of thyroïdal uptake studies. Although there has been no systematic follow-up for radiation-induced malignancy in most of these several million patients, a follow-up has been reported of a small subset of these patients. Holm et al (7) have reported a retrospective study of more than 10,000 patients in Sweden who between 1952 and 1965 received an average of 60  $\mu\text{Ci}$   $^{131}\text{I}$  for diagnostic purposes, resulting in a thyroïdal dose of about 60 rem. Tracer studies were performed mainly on adults; only 5% of the patients were under 20 years at the time of  $^{131}\text{I}$  administration. The expected incidence of thyroid cancer in a control population of 10,000, according to data from the Swedish Cancer Registry, was 8.3, and only 9 were observed. The mean follow-up period for the patients averaged 18 years, ranging from 10 to 25 years. If the risk factors derived from the follow-up of the Hiroshima-Nagasaki survivors or those treated with X-rays in the neck region were applicable, one would have expected a five-fold increase in thyroid cancer in this group—but no increase was found. This study suggests that the same radiation dose to the same region may be less carcinogenic if delivered at a lower dose rate.

Several studies suggest an increase in the incidence of leukemia associated with radiotherapy. In the best known of these studies, Court-Brown (8) reported a five-fold increase in leukemia in patients with ankylosing spondylitis who had received X-ray therapy of the affected sacroiliac joints. What was unusual about this report was that there appeared to be no clear relationship between the excess risk of leukemia and the estimated bone marrow dose.

More recently, there was an International Collaborative Study of more than 31,000 women with cervical cancer, of whom 90% received radiation therapy and the rest did not. In the irradiated group, 15.5 cases of leukemia were expected, but only 13 were observed (9). In the non-irradiated group, two cases of leukemia were observed as compared with the one that was expected. The follow-up was long enough to have included the period of peak leukemia incidence, as observed with the Japanese atom bomb survivors (4). This study (9) would suggest that there is no detectable leukemogenic effect in patients with cervical cancer following radiotherapy. The cohort size of this study is quite comparable to that of Court-Brown (8). It is unclear why radiotherapy would appear to be leukemogenic in one disease and not in another when the therapeutic doses are in the same range although not delivered to identical regions of the body.

### Radiation Workers

What is the evidence for radiation-related malignancies among radiation workers? A report in 1981 of the mortality from cancer and other causes among 1,338 British radiologists who joined radiologic societies between 1897 and 1954 revealed that in those who entered the profession before 1921, the cancer death rate was 75% higher than that of other physicians. Those entering radiology after 1921 had cancer death rates comparable to those of other professionals (10). Although the exposures of the radiologists were not measured, estimates suggest that those who entered the profession between 1920 and 1945 could have received accumulated whole-body doses on the order of 100 to 500 rem.



Another large group of radiation workers studied were men in the American Armed Services trained as radiology technicians during World War II and who subsequently served in that capacity for a median period of 24 months. Description of their training included the statement that "During the remaining two hours of this period the students occupy themselves by taking radiographs of each other in the positions taught them that day" (11). This report noted that the students did not receive a skin erythema dose nor did they show a drop in white count, monitoring procedures which are insensitive to acute doses less than 100 rem. From what we now know, these technicians probably received as much as 50 rem or more during their training and several years of service. Yet a 29-year follow-up of these 6,500 radiology technicians revealed no increase in malignancies when compared with a control group of similar size consisting of Army medical, laboratory, or pharmacy technicians (12).

There is no doubt that early radiation workers were highly exposed. This was due in part to ignorance of the potential hazards associated with high doses of irradiation but also to the absence of convenient monitoring devices. Largely because of the health physics program associated with the Manhattan Project, which had the responsibility for developing the atom bomb, methods for monitoring radiation were developed. At present, the only group receiving occupational radiation exposure that is not monitored are airline crews. In 1957 the American National Council on Radiation Protection recommended that the occupational Maximum Permissible Dose be limited to 5 rem per year. According to the BEIR III report (13), in 1975 96.5% of hospital-based radiation workers and 90% of industrial workers, including those working in reactor power plants or processing nuclear fuels, received less than 1 rem. About 45% of both groups received no measurable radiation. For comparison, a round-trip flight between Los Angeles and Zurich results in each passenger and crew member receiving a dose of about 10 mrem from increased cosmic radiation. Thus, crew members who fly one such flight a week receive yearly radiation doses (0.5 rem) greater than those received by 80% of monitored radiation workers.

## Radon Exposure

Unlike man-made sources of radiation exposure, natural sources of radiation have always been with us. However, at present, there is considerable concern with the levels of radon in homes. Radon, an inert radioactive gas, follows radium in the uranium chain of naturally occurring radionuclides. Part of the concern was generated by the recent appreciation that in a rather large region (Reading Prong) stretching throughout three states in the Northeastern United States, homes exist in which the concentrations of radon coming from the earth below exceed those now permitted in uranium mines. In the United States, the Environmental Protection Agency and the Centers for Disease Control have estimated that as many as 20,000 to 30,000 lung cancer deaths yearly might be due to indoor radon. Are these estimates reasonable? Let us consider what the lung cancer death rate in the United States was before cigarette smoking became common. According to American Cancer Society statistics (14), in 1930 the male and female age-adjusted cancer death rates were 4 and 2 per 100,000 respectively; 50 years later the rates had risen to 72 and 21 per 100,000. Since there is no reason to anticipate a sex-linked difference in lung cancer, the 1930 female rate was

probably closer to the true lung cancer rate in nonsmokers. Was there a marked under-diagnosis of lung cancer among women in 1930? This is not likely since the rate increased only slowly until 1960, when the effects of post World War II smoking among women resulted in a continuously steeper rise in their lung cancer death rates. Furthermore, the age-adjusted lung cancer incidence rate among Mormon women in Utah in 1967-75 was only 4.7 per 100,000 and that of Mormon males 27 per 100,000 (15). Because of religious beliefs, Mormons are supposed to abstain from smoking and use of alcoholic beverages and even caffeine-containing drinks such as coffee and cola. Although the incidence of lung cancer for Mormon males is less than one-half that for the general population of American males during the same period, it does suggest that not all Mormons abstain from smoking. Additionally, under-diagnosis is unlikely in the Mormon community since they have excellent medical care. It is therefore quite likely that the lung cancer death rate in non smokers should be no more than 2-3 per 100,000 or only about 5,000 lung cancer deaths a year in the United States. Since it is extremely unlikely that all lung cancers in nonsmokers are radon-related, it appears that the estimates are probably too high by a factor of up to 10 and tend to underestimate the proven deleterious effects of smoking. Although there has been concern that modern energy efficient homes trap radon, studies have shown that this effect is minimal, accounting for differences in radon concentrations of no more than 20%.

## Chernobyl and Its Aftermath

Fear of radiation has accelerated throughout the world as a consequence of the Chernobyl reactor accident in April, 1986. Two questions are particularly relevant: 1) Could such an accident in a commercial power reactor happen outside the Soviet Union? 2) What are the immediate and potential long-range health problems associated with the accident? The Chernobyl-type RMBK 1000 reactor differs uniquely from those used outside the Soviet Union for power production in that it was based on an early military design for the production of weapons-grade plutonium. It had an unprotected roof through which plutonium-enriched fuel could be unloaded. It was through this unprotected roof that the radioactive plume emerged following explosions. In contrast, power reactors in the West are completely enclosed in a containment structure, which is sealed and is designed to contain the products of a severe accident for an appreciable length of time. To compare the effect of the containment at Three Mile Island (TMI) with the lack of such containment at Chernobyl, it must be appreciated that at TMI, in spite of the damage to the fuel rods which resulted in the release of 30% of the iodine into the primary coolant water, less than 30 Ci  $^{131}\text{I}$  were released to the environment (16). At Chernobyl the release of  $^{131}\text{I}$  the first day according to Soviet information (17), was  $4.5 \times 10^6\text{Ci}$ . At TMI the airborne releases of radioactive cesiums and strontiums were less than  $100 \times 10^{-6}\text{Ci}$  (16) compared to about  $1 \times 10^6\text{Ci}$  at Chernobyl (17). Thus, the importance of adequate containment cannot be overemphasized.

The second feature that is unique to the Chernobyl-type graphite reactor is that it has what is called a "positive void coefficient." If the water is lost in light water moderated reactors (LWR), the chain reaction instantly stops, as it did at TMI. In contrast, in the Chernobyl-type reactor, the loss of water to steam accelerates the chain reaction, which raises the temperature and increases the water loss. Thus, the



reactor tends to "run away" when the water is lost. It was this power surge that led to the explosions at Chernobyl. Thus, a Chernobyl-type accident is not possible in a commercial power reactor in the West.

What about the short- and long-range health consequences of the accident? According to the Soviet report (17), 31 deaths occurred in the immediate period following the accident. This may be compared with the 346 dead, 500 injured, and thousands left homeless in a Mexico City gas-storage explosion in 1984—an accident long since forgotten. What about the potential long-term effects? The most highly exposed were about 25,000 people living between 3 and 15 km from the reactor. Their average radiation dose was about 50 rem. The remaining 100,000 who were evacuated had cumulative exposures averaging only about 5 rem. The next decade might provide the answers as to whether levels of radiation comparable to those received acutely at Hiroshima-Nagasaki but delivered at lower rates will result in the same degree of leukemogenesis. We can but hope that the Soviet scientists are performing the appropriate studies to answer this very important question concerning a dose-rate effect. The large number of cancer deaths predicted to be a consequence of the Chernobyl accident are related to the use of the linear extrapolation hypothesis, which states that a given amount of radiation produces the same number of cancers independent of the number of people who received that dose or the rate at which the dose was delivered. If this hypothesis were applied to another well known carcinogen, it would mean there would be the same number of smoking-induced lung cancers after 20 years among 100 persons each smoking 10,000 cigarettes a year (1 1/2 packs each day) as among one million persons each smoking one cigarette per year. I doubt if anyone really believes linear extrapolation for cigarette smoking, but this hypothesis is widely used for the prediction of radiation effects.

Over the next 70-year period, the 75 million Soviet citizens living within 1,000 km of Chernobyl may receive an increase in radiation exposure about 10% above the usual natural background. In the other European countries, the increased exposures will be even lower, falling to about 1% above natural background in England and France. Are people likely to have an increased cancer death rate because of this increase? In view of the absence of evidence for increased cancer rates associated with up to 10-fold increases in natural background radiation as described earlier, it is most unlikely that this predicted increased exposure would have any measurable effect. After all there has been no concern with living in the Alps and other mountain regions with the resultant increased cosmic radiation.

## Conclusion

There is no doubt that there is widespread fear of radiation at any level. Radiation is considered to be mysterious because one cannot see, hear, or feel it. Nonetheless, with the instrumentation currently available, radiation is probably

measurable at lower amounts than any other known potential carcinogen. It does seem unreasonable to be concerned with radiation doses comparable to variations found in natural background radiation. An unanswered question is what is the minimal dose and dose rate of radiation exposure associated with measurable harmful biologic effects.

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